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Assessing Public Transport Supply Quality: A Comparative Analysis of Analytical Network Process and Analytical Hierarchy Process

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ABSTRACT

This paper delves into the realm of public transport system enhancement, a critical consideration for decision makers due to its profound impact on citizens' lives and government in-vestments. The primary objective is to assess the quality of public bus transport supply and identify the most effective improvements to heighten passenger satisfaction and attract new users. To accomplish this goal, two prominent multi-criteria decision-making approaches, namely the Analytical Network Process (ANP) and the Analytical Hierarchy Process (AHP), were employed, leveraging a dynamic questionnaire survey. The ANP method, recognized for its robustness, takes into account the interrelationships and feedback among various criteria levels, offering a systematic evaluation framework. In contrast, the AHP method overlooks these factors. The adoption of both methods was crucial in obtaining a comprehensive under-standing of experts' perceptions regarding public transport service quality. To illustrate the practical implementation of these approaches, an empirical study was conducted using a re-al-life case. This study serves as a testament to the efficacy of these decision-making methods and underscores their value in the decision-making process. Ultimately, this paper under-scores the significance of prioritizing public transport system improvements as a means to en-rich citizens' lives and bolster government investments.

1. Introduction

Public Transport (PT) system amelioration is becoming the focal point for government, because of its critical impacts on many sides of everyday life. PT conveys many more users in much less space than personal cars, which helps to keep traffic congestion lower, and decreases air pollution per passenger-km than the standard personal cars which carry a single passenger according to (APTA). It

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impacts positively the economy, where users can save individuals a significant amount of money each year in avoided fuel, maintenance, parking, taxes, and other expenses. PT is safer, not only in terms of the safety of the vehicles themselves, which are maintained much more regularly than individual automobiles but also in terms of the time by spending transit time on reading, working, studying or many other activities or just take a nap. However, by increasing PT services, the community also got impacted psychologically and economically. However, many papers have proposed and focused their attention on the quality of PT [1, 2, 3, 4, 5]. For this justifications planners and decision makers seek to straighten out PT as a means of bolstering ridership.

The objective of the study is to enumerate public bus transport supply quality in Budapest city, for this aim two of the most extensive methods of MCDM were selected. MCDM methods were widely applied in different types of PT improvement cases in order to augment users satisfaction, for rail transit [6, 7], for airlines [8, 9], for buses [10, 11, 12] and even for bike-sharing [13, 14].

The first method Is the prestigious Analytical Hierarchy Process (AHP) method was proposed by Saaty [15]as a method of solving complex decision-making problems and it has been used widely to solve spacious species of problems in miscellaneous area [16, 17, 18, 19, 20]. However, the second method is the Analytical Network Process (ANP) method which considers a generalization of AHP [21], where AHP neglects the interrelations among the criteria and deals with them as independent criteria, while ANP considers these interrelations and feedback between the criteria where the criteria behave dependently [21]. In other words, the AHP solves the problem of independence on criteria, and the ANP solves the problem of dependence among criteria. That makes ANP is irreproachable, purposive, and more robust than AHP from decision environment point of view [22]. Both methods are based on a pairwise comparison (PC) survey, however, they differ from each other in the number and types of PCs.

A comparative analysis of these two methods is illustrated with a real data, showing their similarity and some differences.

2. Literature Review

MCDM approaches provides a wide selection of methods such as; AHP, ANP, PROMETHEE, TOPSIS, and ELECTRE, these tools support decision-makers in analyzing attributes and identifying optimum solutions [23, 24, 25, 26]. Similarly, hybrid models have also proven remarkable contributions in the decision-making process. For instance, Turcksin et al. [27] combined two methods for a consensual MCDM model to select the appropriate scenario for a clean vehicle fleet. Wang and Yang, constructed decision-making hybrid model to outsource information systems [28]. While a BWM hybrid model was introduced by Luo and Xing, to build a framework for personnel selection [29].

AHP method is significantly deployed in several studies because of its simplicity and applicability. Evaluators can easily make the pairwise comparison between attributes using Saaty's scale [15]. ANP is a generalized form of AHP that can handle complex problems [21]. It requires a huge number of pairwise comparisons based on the original structure of criteria through the analysis of the interactions between attributes. There are some successful applications of the ANP method [30, 31]. Xu et al. [32] elaborated a hybrid ANP model to evaluate government data sustainability, and it was deployed to serve the strategies' evaluations for railways transportation by Chang et al. [33]. As stated before, AHP is a simple form of ANP which is applied in different research domains. The authors Kabir and Sumi [34] utilized fuzzy-AHP model that handles multiple contradictory decision perspectives and provides reliable results. Furthermore, Duleba et al. [35] in their research adopted F-AHP along with distance-based aggregation approach to evaluate public transportation. Issa et al. [36] combined AHP with Fuzzy TOPSIS to build a consensual decision support system. While in the research, Latterini et al. [37], GIS-AHP model demonstrated high consistency in decision-making process selecting the optimal alternatives.

Public transport network has a viral role in facilitating citizens' life, thus, it is worth a significant consideration from policymakers. Various research aimed to identify the key solution that will improve public transport supply quality and increase ridership ratio together with the reducing road congestion, pollution and fuel consumption [38, 39]. Certainly, the passengers have different preferences for the current public transportation and can help in some ameliorations by providing their opinions and perceptions to the policymakers [2]. For this aim, some research investigated the opinion of different stakeholders including passengers to create efficient models. [40] constructed Grey-AHP models to evaluate and ameliorate the service quality of urban transportation. Bilişik et al. [41] used a hybrid fuzzy methodology to measure customer satisfaction in public transport network in Istanbul city. AHP has been extended and adopted in several fields as well [42, 43].

In transportation, there are various research using MCDM approaches to spotlight the factors impacting transport supply quality. Our paper aims to construct a comparative analysis between the well-known two MCDM methods for the examination of public transport supply quality. The study is constructed as follows:

- The construction of the hierarchical structure of evaluating criteria
- The creation and the conduction of the questionnaire
- The deployment of AHP method
- The deployment of ANP method
- The comparative analysis

Moslem et al. [20] have presented the most recent works related to using AHP for solving transportation problems, however, we highlight the contributions of our current study, the below Table 1. is summarizing the MCDM method deployed in transportation.

Table 1
MCDM application's summary in transportation field

MCDM Method	Methodology	Reference
ANP	Deployment of ANP priorities in transportation	[33]
AHP – ANP	AHP and ANP models to assess the environmental impacts of transport modes	[30]
Fuzzy AHP – Fuzzy TOPSIS	Hybrid model to evaluate customer satisfaction regarding public transportation in Istanbul	[41]
AHP-Kendall	Evaluation of urban public transport by using AHP-Kendall	[2]
AHP – ELECTRE	A comprehensive evaluation of urban transport in Krakow deploying a hybrid AHP-ELECTRE model	[44]
Interval-AHP	Evaluation of urban public transport by using Interval-AHP	[45]
ANP	ANP method for risk assessment in transport infrastructure projects	[31]
AHP	AHP method for the evaluation of innovative ideas for urban transport	[46]
Fuzzy AHP – Interval AHP	Deployment of two AHP approaches for sustainable transport development decision	[47]
Best Worst Method (BWM)	Evaluating modal split by adopting BWM during COVID-19	[48]
Fuzzy AHP	The analysis of the impacts of driver behavior on road safety using F-AHP model	[49]
AHP-BWM	Driver behavior analysis using AHP-BWM model	[50]
BWM	Analyzing modal split by using BWM	[39]
Spherical fuzzy AHP	Evaluation of urban public transport by using Spherical fuzzy AHP	[52]
BWM, AHP and MOORA	Analyzing travel mode by using BWM, AHP and MOORA in grey space	[53]
AHP – PROMETHEE	A comparative study between AIJ and AIP approaches for the aggregation of a group evaluations using the AHP-Group PROMETHEE model	[51]
Pythagorean Fuzzy AHP	Estimating Driver Behavior Measures Related to Traffic Safety by Investigating 2-Dimensional Uncertain Linguistic Data—A Pythagorean Fuzzy AHP	[54]
Parsimonious BWM	Analyzing travel mode by using Parsimonious BWM	[55]
AHP	Evaluating park-and-ride facility location by using AHP	[56]
Grey AHP	Evaluating park-and-ride facility location by using grey AHP	[57]
Grey AHP	Evaluating the most related factors that is affecting recurrent lane change	[58]
AHP – ANP	A comparative analysis between AHP and ANP for the evaluation of public transport supply quality	The proposed model in this work

2.1. A review of the use of multicriteria methods used in public transport system

Recently, MCDM methods are applied to evaluate the urban transport system and improve the quality of service of the system for more sustainable and livable cities [59].

The most popular tools among MCDM methods are AHP, ANP, PROMETHEE, TOPSIS, and ELECTRE, these methods help the decision-makers in evaluating and solving the complex problems by analyzing attributes and alternatives then determining the related weights and best solutions [24].

Creating public transport quality in such urban communities is viewed as a productive solution for blocking complex issues like air pollution, traffic accidents, and congestion, to decide the huge stock quality measures of public transportation, a lot of specialists utilized AHP as an applied system. AHP has been applied based on created questionnaires, that were utilized with respect to the order of hierarchy of quality factors, and as evaluators in Mersin, Turkey. The survey involved decision-makers from both the public and the government. The level of public satisfaction and passenger demand for public transportation has been determined through data analysis [10].

It is essential to examine the public's preferences for improving the urban transportation system from a market and sustainability perspective. This analysis must include setting up and testing a broadly applicable model for decision support, as well as quality and transport fare criteria related to the city's current service. Since the procurement of public inclination was the essential goal, and the issue can be considered as independent direction, AHP was selected as the methodology. There are past exploration aftereffects of applying this strategy on public transport, be that as it may, not in a coordinated model, in which quality and cost contemplations are pairwise looked at. The new model was tested in a case study: surveying the public transport demand in the capital of Jordan, Amman [60].

The decision-maker has faith in the robustness and consistency of AHP approach, which is based on dynamic and sensitivity analysis. The hierarchical structure for rating the criteria is comprehensive and adaptable, and it has the potential to assist decision-makers and others involved in the transportation decision-making process. The public bus transportation system of Budapest (Hungary) was used as a study case, and the data from a 2018 questionnaire survey conducted by transportation experts in Budapest were used to evaluate and rank the most important factors related to the supply quality of public transportation. This penetration could be used to increase passenger satisfaction and bring in new passengers to the public bus system [59] .

Most of the time, passengers and planners have very different ideas about what improvement matters. public interest for public transport improvement can be specified, by breaking down open transport supply quality measures among organizers and the public in Mersin City, Turkey. In order to shed light on the divides that exist between planners and the general public, a methodology that combines the Analytic Hierarchy Process (AHP) and the Spearman correlation method was utilized. The results of the Spearman rank correlation coefficient show that level 2 has a weak positive relationship and level 3 has a strong positive relationship. To obtain more effective results, it is suggested that future studies divide participants into passengers, non-passengers, planner users, and non-users [61]. Fuzzification is more flexible than the conventional AHP method, which uses hierarchical logic to create a system of decision elements that is easy to understand and reduces the uncertainty of responses. The fuzzy-AHP model guarantees that the city's bus system will be improved in accordance with public demand [61] .

An applied method is known as the Interval AHP (IAHP) can deal with the inconsistent and uncertain responses of users by comparing passenger results to those of reference stakeholder groups. Our findings demonstrate that IAHP is capable of supporting a broader strategy for the consensual development of a public transportation system. However, by utilizing this model, an outcome that is more agreeable and, without a doubt, more sustainable than simply employing the conventional AHP method can be achieved [45] .

The fuzzyfication of the scores is conducted because of the citizen evaluator pattern. The fuzzyAHP (FAHP) model has been tested in a real-world situation with the case study of Amman (Jordan). It decides to consider the demand as a Multi-Criteria Decision Making (MCDM) problem and surveying the citizens' preferences provides the results for decision support. Public transport demand depends on two main issues, quality, and price of the transportation [62] .

The grey-AHP model assumes an efficient contrivance to facilitate the public transport system's supply quality evaluation, especially when respondents are non-experts. Also, Alkharabsheh et al. [60] estimate and rank the public transport system's supply quality criteria by adopting the proposed model for a real-world case study (Amman city, Jordan). The study's findings demonstrate the developed strategy's efficacy and adaptability to improving public transportation quality.

Parsimonious AHP (PAHP) is a recently created methodology that combines the simplicity of direct evaluations with the consistency and reliability of the Analytic Hierarchy Process (AHP). The new procedure is more reliable than satisfaction measured by direct evaluations because it takes less time and costs less than the AHP while providing the same benefits. As a result, the model we've proposed can be used in both theoretical and practical situations.

Based on numerical experiments, MOORA has been identified as the best MCDM method in terms of computational time and problem setup time. The Grey AHP-MOORA model is used to solve a real-world transportation problem and is primarily useful for supporting strategic decision plans for improving the urban transportation system in terms of sustainability [40].

To increase commuter satisfaction and attract non-commuters, improving public transportation systems may require skillful strategic planning. BWM is applied to acquire the weight scores for the assessment of the public transportation arrangement of Budapest. The decision matrix for the expert evaluations is then created using grey MOORA. The grey AHP is used to conclude the evaluation of Budapest's public transportation system. That implies an adopted grey decision model of the BWM, AHP, and MOORA is directed to complete this reason and assess the public transportation framework in the capital of Hungary, Budapest, by checking the productivity and approval of the proposed took on a grey decision model [53].

3. Methodology

3.1 AHP method

AHP is conceptually easy to use; and it has been implemented in different scientific research fields, in medicine [63, 64], in agriculture [65, 66] , in construction engineering [67, 68] (, in software engineering [69], in transportation [70, 71]. However, public transport system is a quite complex and AHP method was widely applied for obviating its complex problems [72, 73, 74. The objective of this study is to delineate and enumerate the most important public bus transport supply quality in Budapest. AHP method was implemented based on PC questionnaire survey where the experts in the related field was the evaluator group. The evaluators used Saaty's judgment scale of relative importance for PCs by comparing the criteria that belong to the same branch in AHP method and comparing the criteria with all other criteria in ANP method. It is an important step to use carefully Saaty's scale, for instance, number three means: "moderate importance", then it is necessary to explain that "moderate" actually means three times, and from the perspective of subjective understanding, three times is really quite a lot. The Saaty scale is one of the most criticized parts of the AHP. Incorrect use of the scales then leads to inconsistencies [75].

AHP utilizes a particular attribute of paired comparison (PC) matrices. The PC matrix is a quadratic, reciprocal, and consistent theoretical matrix [75]. In order for matrix A to be considered consistent, all of its elements must be positive, transitive, and reciprocal, as shown in equations (1) and (2):

$$a_{ij} = \frac{1}{a_{ji}}, \quad (1)$$

$$a_{ik} = a_{ij} \cdot a_{jk}. \quad (2)$$

The dominant eigenvector of such PC matrix is trivial to be determined by Saaty's eigenvector method [75], if A is a consistent matrix, then the eigenvector w can be found by finding its maximum eigenvalue ($\lambda_{\max}$) through eq. (3) and (4):

$$A\,w = \lambda_{\max}\,w. \quad (3)$$

$$(A - \lambda_{\max}\,I)\,w = 0, \quad (4)$$

The concept of uncertainty in judgments is accounted for in the AHP method by considering the principal eigenvalue and the consistency index [75]. To measure the degree of consistency, Saaty introduced the Consistency Index (CI) as the deviation, which can be computed using equation (5):

$$\mathrm{CI} = \frac{\lambda_{\max} - \mathrm{n}}{\mathrm{n} - 1}, \quad (5)$$

where λ max is the largest eigenvalue of the PC matrix and n is the number of classes. Consistency Ratio (CR) is a measure of consistency of PC matrix, where its value has to be under 0.1 in order to achieve the inconsistency for the PC matrix and it is given by eq. (6):

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}, \quad (6)$$

where RI is the Ratio Index that represent the random consistency index. The value of RI for different n values is given in [75].

Given that multiple evaluators participated in the PC survey, it is necessary to combine their individual weights. To prevent rank reversal and ensure accuracy, it is recommended to calculate the geometric mean of the evaluator scores to determine the aggregated results [76].

To ensure no rank reversal and to aggregate individual weights from multiple evaluators in the PC survey, it is recommended to calculate the geometric mean of their respective scores to determine the aggregate results [76].

If "h" evaluators exist in the procedure, the aggregated weight is given in eq (7):

$$\mathrm{f}(\mathrm{x}_1, \mathrm{x}_2, \dots, \mathrm{x}_\mathrm{h}) = \sqrt[\mathrm{h}]{\prod_{\mathrm{k}=1}^{\mathrm{h}} \mathrm{x}_\mathrm{k}}. \quad (7)$$

where $\mathrm{x}_1, \mathrm{x}_2, \dots, \mathrm{x}_\mathrm{h}$ denotes entries, in the same position (i, j), of PC matrices, filled in by the k-th decision maker. As consistency was acceptable, the final score determination can be calculated through equation (8):

$$w_{A_i} = \frac{w_j}{w} \frac{w_{ij}}{\sum_{k=1}^{n} w_{ik}} = \left(\frac{w_j}{w} \frac{1}{\sum_{k=1}^{n} w_{ik}}\right) w_{ij} \quad (8)$$

where j = 1 ,…, m and $w = \sum_{i=1}^{m} w_j$; $w_j > 0$ (*j* = 1,…, *m*) represents the related weight coordinate from the previous level; $w_{ij} > 0$ (*i* = 1,…, *n*) is the eigenvector computed from the matrix in the current level, w_{Ai} (*i* = 1,…, *n*) is the calculated weight score of current level's elements.

3.2. ANP method

AHP is indeed conceptually easy to use; however, its strict hierarchical structure cannot deal the complexities of many real-world problems. As a solution for these complex problems, Saaty created ANP as generalized form of AHP [22, 77]. ANP also applied based on PC survey, however, the PC survey was constructed of 276 PCs which represent all interrelations and feedbacks between the twenty-four criteria, and Saaty's scale was used by the experts to perform the comparisons and the final score determination was calculated through equation (7). The priority vectors are entered in the appropriate columns of the super matrix to obtain the relative priorities of various classes with interdependent influences between the criteria. The ANP analysis was designed in Super Decisions software and Figure 1 depicts the Supermatrix of the approach.

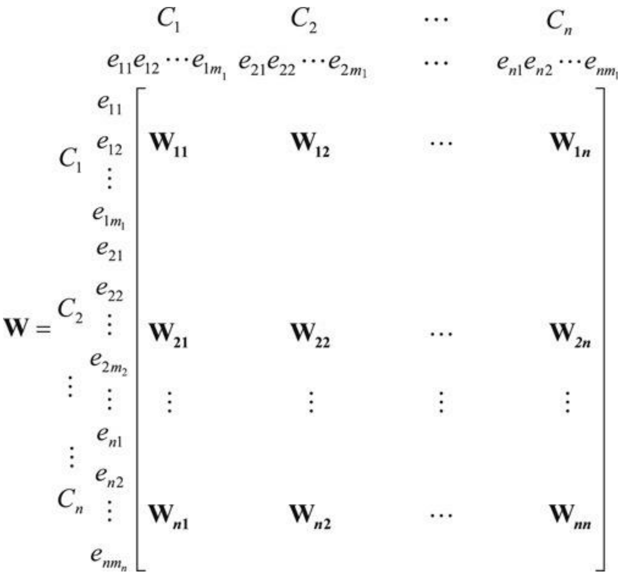

Fig. 1. Supermatrix of ANP [21]

3. Results

For applying the AHP method the hierarchical structural model as shown in (Figure 1) was used and applied for elaborating the public bus transport situation in Budapest city. This hierarchical model was constructed by Duleba and his colleagues [78] (Figure 2). The hierarchical model of supply quality consists of three levels with total twenty-four criteria, regarding to the number of criteria twenty-seven PCs were constructed for the questionnaire survey, and it was evaluated by ten experts, the experts were researchers in transportation and logistics filed, moreover, all of them hold a PhD degree. The questionnaire survey was evaluated in February 2018 and analyzed in March 2018. The consistency ratio (CR) was less than 0.1, thus it was acceptable to complete the AHP analysis. Sensitivity analysis was performed by changing the weight of each main criteria to test the stability of the rank and it was robust without change.

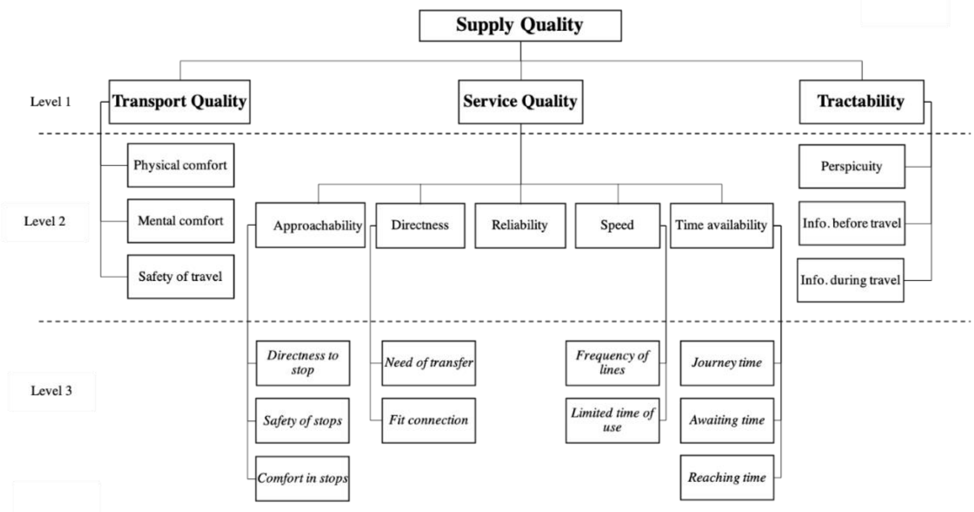

Fig. 2. The hierarchical structure of criteria for public bus transport supply quality [78]

Ranking of different criteria in public bus transportation systems in terms of their development is summarized in Tables 2–4.

Table 2
Priority ranking of criteria for Level 1 based on AHP.

Criteria	Weight	Rank
Service quality	0,2374	3
Transport Quality	0,2785	2
Tractability	0,4841	1

In the first level, “Service Quality” was the most essential issue to be developed, followed by “Transport Quality” and “Tractability” as shown in Table 4. The second level promote “Reliability” as the most critical issue followed by “Time availability” and “Mental comfort”. However, the “Physical comfort” and “Perspicuity” were that important in the experts’ point of view. The priorities in the third level highlight the “Limited time of use” as the most important issue to be developed and it was followed by “Directness to stop” and “Fit connection”. While “Comfort in stop”, “Safety in stop” and “Need for transfer” were the last important issues.

Table 3
Priority ranking of criteria for Level 2 based on AHP.

Criteria	Weight	Rank
Approachability	0,0323	9
Directness	0,0596	7
Time availability	0,0585	8
Speed	0,0660	6
Reliability	0,0210	11
Physical comfort	0,1370	4
Mental comfort	0,1166	5
Safety of travel	0,0249	10
Perspicuity	0,1666	1
Information before travel	0,1610	2
Information during travel	0,1565	3

Table 4
Priority ranking of criteria for Level 3 based on AHP.

Criteria	**Weight**	**Rank**
Directness to stops	0,0056	6
Safety of stops	0,0085	8
Comfort in stops	0,0182	7
Need of transfer	0,0348	2
Fit connection	0,0248	3
Frequency of lines	0,0132	10
Limited time of use	0,0453	4
Journey time	0,0262	1
Awaiting time	0,0170	9
Time to reach stops	0,0228	5

ANP was applied based on 276 PCs in order to consider the interrelations and feedbacks between the criteria.

The actual finding of links between criteria is done by experts during estimating the 276 PCs. The analysis results highlighted 151 interrelations between different criteria and according to these outcomes, the analytic network structure was constructed as shown in (Figure 3), where the network model contains (276-125 = 151 interrelations). Indeed, evaluating 276 PCs quite a lot of pressure is put on the experts, however, this is one the drawbacks of ANP and it generate more accurate results because all interrelations are tested among all criteria.

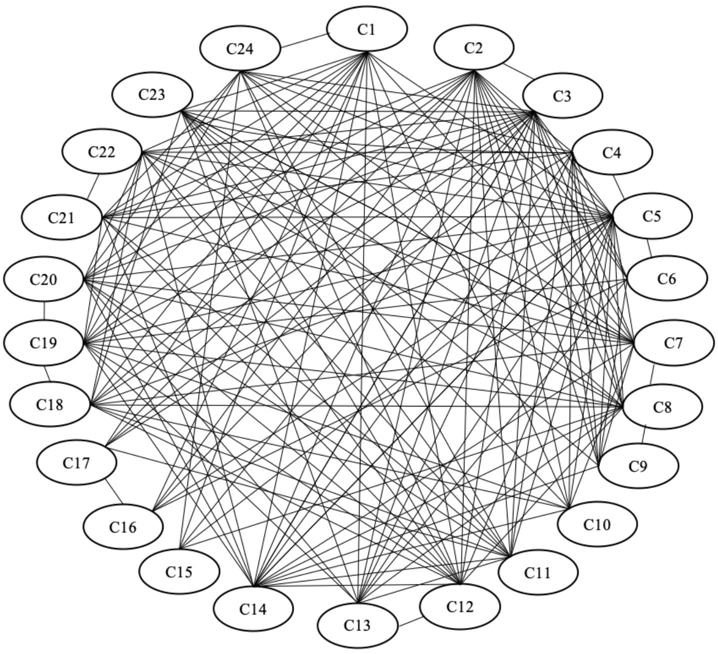

Fig. 3. The network structure of criteria for public bus transport supply quality criteria

The priority ranking of supply quality criteria that are presented in Table 5. Has been adopted by applying ANP and using Super Decisions software, which provided the preference ranking for public bus transport system criteria and most significant criteria regarding to the applied analysis was "Tractability" followed by "Service quality", "Transport quality", "Information before travel" and "Perspicuity". However, "Comfort in stops" was ranked as the most insignificant issue to be developed and it was followed by other inconsequential issues like “Directness to stops”, “Need for transfer”, “Reliability” and “Time to reach stops”.

Table 5
Priority ranking of public bus transport supply quality criteria based on ANP.

Rank	Criteria	Normalized Weight
1	Tractability	0.0993
2	Transport Quality	0.0751
3	Service Quality	0.0736
4	Perspicuity	0.0601
5	Information before travel	0.0541
6	Information during travel	0.0531
7	Physical comfort	0.0503
8	Mental comfort	0.0451
9	Speed	0.0448
10	Directness	0.0412
11	Time availability	0.0387
12	Safety of travel	0.0382
13	Need of transfer	0.0357
14	Journey time	0.0341
15	Approachability	0.0331
16	Limited time of use	0.0327
17	Fit connection	0.0311
18	Time to reach stops	0.0308
19	Reliability	0.0267
20	Safety of stops	0.0242
21	Awaiting time	0.0235
22	Frequency of lines	0.0191
23	Comfort in stops	0.0179
24	Directness to stops	0.0169

4. Discussion and Conclusions

In this study, ANP based methodology that supports the independency and feedback between criteria in different levels of the network and AHP which is more efficient from mathematical point of view when the decision structure is basically hierarchical, have been used to evaluate public bus transport supply quality in Budapest city. The findings from AHP spot the light on “Service Quality” as the most critical issue to be developed, while ANP analysis results highlighted “Tractability” as the most significant issue to be developed. However, when we look at the first three most significant criteria in both outcomes, we realize that they ranked the same three criteria, which are “Service Quality”, “Transport Quality” and “Tractability”. Even the last insignificant three criteria there is one common criteria “Comfort in stop”.

AHP does not consider the dependencies and interrelations among criteria. However, real life complex problems usually contain dependence or feedback between elements.

Implementing ANP method is quite more complicated and robust than AHP method, because of its large number of comparisons, and the inconsistency check also difficult due to the super matrix. The experts stated that the ANP questionnaire is quite complicated (276 comparisons) and require long time to evaluate the criteria. However, AHP questionnaire conceptually easier, but its strict hierarchical structure cannot handle the complexities of many real-world problems. The most important criteria based on ANP outcomes was “Tractability”, followed by “Transport Quality” and

“Service Quality”, which are the main criteria in the hierarchical structure of AHP structure. The main advantage of ANP is that it can handle complex decision-making scenarios that involve interdependent and feedback relationships between the criteria. ANP allows decision-makers to model complex systems with feedback loops and interconnections between criteria, which can be difficult to represent in an AHP model. Furthermore, ANP allows for flexibility in decision-making by allowing decision-makers to adjust their priorities and criteria as new information becomes available. This can be particularly useful in dynamic decision-making scenarios where priorities and criteria may change over time.

The age of the adopted survey does reduce its relevance and applicability to the current situation. It is possible that there have been changes in the quality of transport in Budapest in the past five years, and those changes may affect the study's findings. Therefore, it is important to consider the limitations of the study when interpreting its results and applying them to current situations.

For further research, authors recommend to apply another method based on the detected interrelations between the criteria in different levels. Moreover, AHP and ANP can be adopted in fuzzy environments to avoid the evaluator’s hesitancy [79-81]. Also using suitable operation to aggregate the individual perspective, such as, Complex Hesitant Fuzzy Sets and Interval-valued Pythagorean fuzzy information aggregation based on Aczel-Alsina and will provide more efficient results [82, 83, 84].

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Conflicts of Interest
The authors declare no conflicts of interest.

References

[1] Bischoff, J., & Maciejewski, M. (2019). Current and Future Dynamic Passenger Transport Services-Modeling, Simula-tion, and Optimization in a Sustainable Transport System. Sustainable Transportation and Smart Logistics, 2019, 337-360. https://doi.org/10.1016/B978-0-12-814242-4.00013-2

[2] Duleba, S., & Moslem, S. (2018). Sustainable Urban Transport Development with Stakeholder Participation, an AHP-Kendall Model: A Case Study for Mersin. Sustainability, 10(10), 3647 https://doi.org/10.3390/su10103647

[3] Wong, R. C. P., Szeto, W. Y., Yang, L., Li, Y. C., & Wong, S. C. (2018). Public transport policy measures for improving el-derly mobility. Transport policy, 63, 73-79. https://doi.org/10.1016/j.tranpol.2017.12.015

[4] Gatta V., & Marcucci E. (2007). Quality and public transport service contracts. European Transport, (36), pp. 92-106. http://hdl.handle.net/10077/5952

[5] Eboli, L., & Mazzulla, G. (2008). Willingness-to-pay of public transport users for improvement in service quality, European Transport, 38, 107-118.

[6] Santarremigia, F. E., Molero, G. D., Poveda-Reyes, S., & Aguilar-Herrando, J. (2018). Railway safety by designing the layout of inland terminals with dangerous goods connected with the rail transport system. Safety Science, 110, 206-216. https://doi.org/10.1016/j.ssci.2018.03.001

[7] Ghosh, P., & Ojha, M. K. (2017). Determining passenger satisfaction out of platform-based amenities: A study of Kanpur Central Railway Station. Transport Policy, 60, 108-118. https://doi.org/10.1016/j.tranpol.2017.09.007

[8] Tsafarakis, S., Kokotas, T., & Pantouvakis, A. (2018). A multiple criteria approach for airline passenger satisfaction measurement and service quality improvement. Journal of Air Transport Management, 68, 61-75. https://doi.org/10.1016/j.jairtraman.2017.09.010

[9] Lin, Z., & Vlachos, I. (2018). An advanced analytical framework for improving customer satisfaction: A case of air pas-sengers. Transportation Research Part E: Logistics and Transportation Review, 114, 185-195. https://doi.org/10.1016/j.tre.2018.04.003
[10] Moslem, S., & Duleba, S. (2018). Application of AHP for evaluating passenger demand for public transport improvements in Mersin, Turkey. Pollack Periodica, 13(2), 67-76. https://doi.org/10.1556/606.2018.13.2.7
[11] Mavi, R. K., Zarbakhshnia, N., & Khazraei, A. (2018). Bus rapid transit (BRT): A simulation and multi criteria decision making (MCDM) approach. Transport Policy, 72, 187-197. https://doi.org/10.1016/j.tranpol.2018.03.010
[12] Aydın, S., & Kahraman, C. (2014). Vehicle selection for public transportation using an integrated multi criteria decision making approach: A case of Ankara. Journal of Intelligent & Fuzzy Systems, 26(5), 2467-2481. https://doi.org/10.3233/IFS-130917
[13] Jahanshahi, D., Minaei, M., Kharazmi, O. A., & Minaei, F. (2019). Evaluation and Relocating Bicycle Sharing Stations in Mashhad City using Multi-Criteria Analysis. International Journal of Transportation Engineering, 6(3), 265-283. https://doi.org/10.22119/ijte.2018.96377.1365
[14] Kabak, M., Erbaş, M., Çetinkaya, C., & Özceylan, E. (2018). A GIS-based MCDM approach for the evaluation of bike-share stations. Journal of Cleaner Production, 201, 49-60. https://doi.org/10.1016/j.jclepro.2018.08.033
[15] Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology, 15(3), 234-281. https://doi.org/10.1016/0022-2496(77)90033-5
[16] Chang, Y., Yang, Y., & Dong, S. (2018). Comprehensive Sustainability Evaluation of High-Speed Railway (HSR) Construction Projects Based on Unascertained Measure and Analytic Hierarchy Process. Sustainability, 10(2), 408. https://doi.org/10.3390/su10020408
[17] Singh, A., & Prasher, A. (2017). Measuring healthcare service quality from patients' perspective: using Fuzzy AHP ap-plication. Total Quality Management & Business Excellence, 30(3) 1-17. https://doi.org/10.1080/14783363.2017.1302794
[18] Kumar, A., Sah, B., Singh, A. R., Deng, Y., He, X., Kumar, P., & Bansal, R. C. (2017). A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. Renewable and Sustainable Energy Reviews, 69, 596-609 https://doi.org/10.1016/j.rser.2016.11.191
[19] Subramanian, N., & Ramanathan, R. (2012). A review of applications of Analytic Hierarchy Process in operations man-agement. International Journal of Production Economics, 138(2), 215-241. https://doi.org/10.1016/j.ijpe.2012.03.036
[20] Moslem, S., Saraji, M. K., Mardani, A., Alkharabsheh, A., Duleba, S., & Esztergár-Kiss, D. (2023). A Systematic Review of Analytic Hierarchy Process Applications to Solve Transportation Problems: From 2003 to 2019. IEEE Access, 11, 11973-11990. https://doi.org/10.1109/ACCESS.2023.3234298
[21] Saaty, T. L. (2005) Theory and applications of the analytic network process: decision making with benefits, opportunities, costs, and risks. RWS publications.
[22] Saaty, T. L. (1996) Decision making with dependence and feedback, The Analytic Network Process, RWS Publications, Pittsburgh.
[23] Corrente, S., Greco, S. and Słowiński, R. (2013). Multiple Criteria Hierarchy Process with ELECTRE and PROMETHEE. Omega, 41(5), 820-846. https://doi.org/10.1016/j.omega.2012.10.009
[24] Bongo, M. F., Alimpangog, K. M. S., Loar, J. F., Montefalcon, J. A., & Ocampo, L. A. (2018). An application of DEMATEL-ANP and PROMETHEE II approach for air traffic controllers' workload stress problem: A case of Mactan Civil Aviation Authority of the Philippines. Journal of Air Transport Management, 68, 198-213. https://doi.org/10.1016/j.jairtraman.2017.10.001
[25] Oubahman, L., & Duleba, S. (2021). Review of PROMETHEE method in transportation. Production Engineering Archives, 27(1), 69-74. https://doi.org/10.30657/pea.2021.27.9
[26] Chrysafis, K. A., Theotokas, I. N. & Lagoudis, I. N. (2022). Managing fuel price variability for ship operations through contracts using fuzzy TOPSIS. Research in Transportation Business and Management, 100778. https://doi.org/10.1016/j.rtbm.2021.100778
[27] Turcksin, L., Bernardini, A. & Macharis, C. (2011). A combined AHP-PROMETHEE approach for selecting the most appropriate policy scenario to stimulate a clean vehicle fleet. Procedia - Social and Behavioral Sciences, 20, 954-965. https://doi.org/10.1016/j.sbspro.2011.08.104.
[28] Wang, J. J., & Yang, D. L. (2006). Using a hybrid multi-criteria decision aid method for information systems outsourcing. Computers and Operations Research, 34(12), 3691-3700. https://doi.org/10.1016/j.cor.2006.01.017
[29] Luo, S., Zhi, X., & L. Ning (2019). A Hybrid Decision Making Framework for Personnel Selection Using BWM, MABAC and PROMETHEE. International Journal of Fuzzy Systems, 21(8), 2421-2434. https://doi.org/10.1007/s40815-019-00745-4

[30] Brožová, H., & Ůžička, M. (2010). The AHP and ANP models for transport environmental impacts assessment. WSEAS Transactions on Power Systems, 5(3), 233-242.
[31] Yucelgazi, F., & Yitmen, İ. (2019). An ANP Model for Risk Assessment in Large-Scale Transport Infrastructure Projects. Arabian Journal for Science and Engineering, 44(5), 4257-4275. https://doi.org/10.1007/s13369-018-3314-z
[32] Xu, J., Li, L., & Ren, M. (2022). A Hybrid ANP Method for Evaluation of Government Data Sustainability. Sustainability, 14(2), 1-32. https://doi.org/10.3390/su14020884
[33] Chang, Y. H., Wey, W. M., & Tseng, H. Y. (2009). Using ANP priorities with goal programming for revitalization strate-gies in historic transport: A case study of the Alishan Forest Railway. Expert Systems with Applications, 36(4), 8682-8690. https://doi.org/10.1016/j.eswa.2008.10.024.
[34] Kabir, G., & Sumi, R. S. (2014). Power substation location selection using fuzzy analytic hierarchy process and PRO-METHEE: A case study from Bangladesh, Energy, 72, 717-730. https://doi.org/10.1016/j.energy.2014.05.098
[35] Duleba, S., Alkharabsheh, A. & Gündoğdu, F. K. (2021). Creating a common priority vector in intuitionistic fuzzy AHP: a comparison of entropy-based and distance-based models, Annals of Operations Research, 318, 163–187. https://doi.org/10.1007/s10479-021-04491-5
[36] Issa, U., Saeed, F., Miky, Y., Alqurashi, M., & Osman, E. (2022). Hybrid AHP-fuzzy TOPSIS approach for selecting deep excavation support system. Buildings, 12(3), 295. https://doi.org/10.3390/buildings12030295
[37] Latterini, F., Stefanoni, W., Venanzi, R., Tocci, D., & Picchio, R. (2022). GIS-AHP approach in forest logging planning to apply sustainable forest operations. Forests, 13(3), 484. https://doi.org/10.3390/f13030484
[38] Soltanpour, A., Mesbah, M., & Habibian, M. (2018). Perceived Service Quality in Urban Rail Transit: a Comparison of Structural Equation Models, 1-18.
[39] Duleba, S., Moslem, S., & Esztergár-Kiss, D. (2021). Estimating commuting modal split by using the Best-Worst Method. European Transport Research Review, 13(1), 29. https://doi.org/10.1186/s12544-021-00489-z
[40] Moslem, S., & Çelikbilek, Y. (2020). An integrated grey AHP-MOORA model for ameliorating public transport service quality. European Transport Research Review, 12, 1-13. https://doi.org/10.1186/s12544-020-00455-1
[41] Bilişik, Ö. N., Erdoğan, M., Kaya, İ., & Baraçlı, H. (2013). A hybrid fuzzy methodology to evaluate customer satisfaction in a public transportation system for Istanbul. Total Quality Management & Business Excellence, 24(9-10), 1141-1159. https://doi.org/10.1080/14783363.2013.809942
[42] De Souza, L. P., Gomes, C. F. S., De & Barros, A. P. (2018). Implementation of new hybrid AHP-TOPSIS-2N method in sorting and prioritizing of an it CAPEX project portfolio. International Journal of Information Technology & Decision Making, 17(04), 977-1005. https://doi.org/10.1142/S0219622018500207
[43] Dos Santos, M., de Araújo Costa, I. P., & Gomes, C. F. S. (2021). Multicriteria decision-making in the selection of war-ships: a new approach to the AHP method. International Journal of the Analytic Hierarchy Process, 13(1). https://doi.org/10.13033/ijahp.v13i1.833
[44] Kiciński, M. & Solecka, K. (2018). Application of MCDA/MCDM methods for an integrated urban public transpor-tation system - case study, city of Cracow. Archives of Transport, 46(2), 71-84. https://doi.org/10.5604/01.3001.0012.2107
[45] Ghorbanzadeh, O., Moslem, S., Blaschke, T., & Duleba, S. (2018). Sustainable urban transport planning considering dif-ferent stakeholder groups by an interval-AHP decision support model. Sustainability, 11(1), 9. https://doi.org/10.3390/su11010009
[46] Nalmpantis, D., Roukouni, A., Genitsaris, E., Stamelou, A., & Naniopoulos, A. (2019). Evaluation of innovative ideas for Public Transport proposed by citizens using Multi-Criteria Decision Analysis (MCDA). European Transport Research Review, 11(1), 1-16. https://doi.org/10.1186/s12544-019-0356-6
[47] Moslem, S., Ghorbanzadeh, O., Blaschke, T., & Duleba, S. (2019). Analysing stakeholder consensus for a sustainable transport development decision by the fuzzy AHP and interval AHP. Sustainability, 11(12), 3271. https://doi.org/10.3390/su11123271
[48] Moslem, S., Campisi, T., Szmelter-Jarosz, A., Duleba, S., Nahiduzzaman, K. M., & Tesoriere, G. (2020). Best-worst method for modelling mobility choice after COVID-19: evidence from Italy. Sustainability, 12(17), 6824. https://doi.org/10.3390/su12176824
[49] Farooq, D., Moslem, S., Faisal Tufail, R., Ghorbanzadeh, O., Duleba, S., Maqsoom, A., & Blaschke, T. (2020). Analyzing the importance of driver behavior criteria related to road safety for different driving cultures. International journal of environmental research and public health, 17(6), 1893. https://doi.org/10.3390/ijerph17061893
[50] Moslem, S., Farooq, D., Ghorbanzadeh, O., & Blaschke, T. (2020). Application of the AHP-BWM model for evaluating driver behavior factors related to road safety: A case study for Budapest. Symmetry, 12(2), 243. https://doi.org/10.3390/sym12020243

[51] Oubahman, L., & Duleba, S. (2022). A Comparative Analysis of Homogenous Groups' Preferences by Using AIP and AIJ Group AHP-PROMETHEE Model. Sustainability, 14(10), 1-19. https://doi.org/10.3390/su14105980

[52] Duleba, S., Kutlu Gündoğdu, F., & Moslem, S. (2021). Interval-valued spherical fuzzy analytic hierarchy process method to evaluate public transportation development. Informatica, 32(4), 661-686. https://doi.org/10.15388/21-INFOR451

[53] Çelikbilek, Y., Moslem, S., & Duleba, S. (2022). A combined grey multi criteria decision making model to evaluate public transportation systems. Evolving Systems, 14, 1-15. https://doi.org/10.1007/s12530-021-09414-0

[54] Farooq, D., & Moslem, S. (2022). Estimating Driver Behavior Measures Related to Traffic Safety by Investigating 2-Dimensional Uncertain Linguistic Data-A Pythagorean Fuzzy Analytic Hierarchy Process Approach. Sustainability, 14(3), 1881 https://doi.org/10.3390/su14031881

[55] Moslem, S. (2023). A Novel Parsimonious Best Worst Method for Evaluating Travel Mode Choice. IEEE Access, 11, 16768-16773. https://doi.org/10.1109/ACCESS.2023.3242120

[56] Ortega, J., & Moslem, S. (2023). Decision support system for evaluating park & ride system using the analytic hierarchy process (AHP) method. Urban, Planning and Transport Research, 11(1), 2194362. https://doi.org/10.1080/21650020.2023.2194362

[57] Ortega, J., Moslem, S., Tóth, J., & Ortega, M. (2023). A two-phase decision making based on the grey analytic hierarchy process for evaluating the issue of park-and-ride facility location. Journal of Urban Mobility, 3, 100050. https://doi.org/10.1016/j.urbmob.2023.100050

[58] Çelikbilek, Y., & Moslem, S. (2023). A grey multi criteria decision making application for analyzing the essential reasons of recurrent lane change. OPSEARCH, 1-26. https://doi.org/10.1007/s12597-023-00640-

[59] Moslem, S. (2020). Analyzing public involvement in urban transport decision making by MCDM methodology. PhD dissertation. Budapest University of Technology and Economics.

[60] Alkharabsheh, A., Moslem, S., Oubahman, L., & Duleba, S. (2021). An integrated approach of multi-criteria decision-making and grey theory for evaluating urban public transportation systems. Sustainability, 13(5), 2740. https://doi.org/10.3390/su13052740

[61] Moslem, S., & Duleba, S. (2019). Sustainable urban transport development by applying a fuzzy-AHP model: a case study from Mersin, Turkey. Urban Science, 3(2), 55. https://doi.org/10.3390/urbansci3020055

[62] Alkharabsheh, A., Moslem, S., & Duleba, S. (2022). Analyzing public travel demand by a fuzzy analytic hierarchy process model for supporting transport planning. Transport, 37(2), 110-120. https://doi.org/10.3846/transport.2022.15881

[63] Pauer, F., Schmidt, K., Babac, A., Damm, K., Frank, M., & von der Schulenburg, J. M. G. (2016). Comparison of different approaches applied in Analytic Hierarchy Process-an example of information needs of patients with rare diseases. BMC medical informatics and decision making, 16(1), 117. https://doi.org/10.1186/s12911-016-0346-8

[64] Maruthur, N. M., Joy, S. M., Dolan, J. G., Shihab, H. M., & Singh, S. (2015). Use of the analytic hierarchy process for medi-cation decision-making in type 2 diabetes. PloS one, 10(5), e0126625 https://doi.org/10.1371/journal.pone.0126625

[65] García, J. L., Alvarado, A., Blanco, J., Jiménez, E., Maldonado, A. A., & Cortés, G. (2014). Multi-attribute evaluation and selection of sites for agricultural product warehouses based on an analytic hierarchy process. Computers and Electronics in Agriculture, 100, 60-69. https://doi.org/10.1016/j.compag.2013.10.009

[66] Okada, H. I. R. O. A. K. I., Styles, S. W., & Grismer, M. E. (2008). Application of the Analytic Hierarchy Process to irrigation project improvement: Part I. Impacts of irrigation project internal processes on crop yields. Agricultural Water Management, 95(3), 199-204. https://doi.org/10.1016/j.agwat.2007.10.003

[67] Raviv, G., Shapira, A., & Fishbain, B. (2017). AHP-based analysis of the risk potential of safety incidents: Case study of cranes in the construction industry. Safety science, 91, 298-309. https://doi.org/10.1016/j.ssci.2016.08.027

[68] Ahmed, S., Vedagiri, P., & Rao, K. K. (2017). Prioritization of pavement maintenance sections using objective based an-alytic hierarchy process. International Journal of Pavement Research and Technology, 10(2), 158-170. https://doi.org/10.1016/j.ijprt.2017.01.001.

[69] Davis, L., & Williams, G. (1994). Evaluating and selecting simulation software using the analytic hierarchy process. In-tegrated manufacturing systems, 5(1), 23-32. https://doi.org/10.1108/09576069410050314.

[70] Hamurcu, M., & Eren, T. (2018). Transportation planning with analytic hierarchy process and goal programming. In-ternational Advanced Researches and Engineering Journal, 2(2), 92-97.

[71] López-Iglesias, E., Peon, D., & Rodriguez-Alvarez, J. (2018). Mobility innovations for sustainability and cohesion of ru-ral areas: A transport model and public investment analysis for Valdeorras (Galicia, Spain). Journal of Cleaner Production, 172, 3520-3534. https://doi.org/10.1016/j.jclepro.2017.05.149

[72] Duleba, S., & Moslem, S. (2019). Examining Pareto optimality in analytic hierarchy process on real Data: An application in public transport service development. Expert Systems with Applications, 116, 21-30. https://doi.org/10.1016/j.eswa.2018.08.049

[73] Mugion, R. G., Toni, M., Raharjo, H., Di Pietro, L., & Sebathu, S. P. (2018). Does the service quality of urban public transport enhance sustainable mobility?. Journal of Cleaner Production, 174, 1566-1587. https://doi.org/10.1016/j.jclepro.2017.11.052

[74] Singh, T., Patnaik, A., Chauhan, R., & Chauhan, P. (2018). Selection of brake friction materials using hybrid analytical hierarchy process and vise Kriterijumska Optimizacija Kompromisno Resenje approach. Polymer Composites, 39(5), 1655-1662. https://doi.org/10.1002/pc.24113

[75] Saaty T. L. (1980) The Analytic Hierarchy Process; McGraw-Hill, New York, NY. https://doi.org/10.21236/ADA214804

[76] Aczél, J., & Saaty, T.L. (1983). Procedures for synthesizing ratio judgements. Journal of Mathematical Psychology, 27(1), 93-102 https://doi.org/10.1016/0022-2496(83)90028-7

[77] Saaty, T. L., & Takizawa, M. (1986). Dependence and independence: From linear hierarchies to nonlinear networks. European journal of operational research, 26(2), 229-237 https://doi.org/10.1016/0377-2217(86)90184-0

[78] Duleba, S., Mishina, T., & Shimazaki, Y. (2012). A dynamic analysis on public bus transport's supply quality by using AHP. Transport, 27, 268-275. https://doi.org/10.3846/16484142.2012.719838

[79] Moslem, S., Stević, Ž., Tanackov, I., & Pilla, F. (2023). Sustainable development solutions of public transportation: An integrated IMF SWARA and Fuzzy Bonferroni operator. Sustainable Cities and Society, 93, 104530. https://doi.org/10.1016/j.scs.2023.104530

[80] Duleba, S., & Moslem, S. (2021). User satisfaction survey on public transport by a new PAHP based model. Applied Sciences, 11(21), 10256. https://doi.org/10.3390/app112110256

[81] Senapati, T., & Yager, R. R. (2020). Fermatean fuzzy sets. Journal of Ambient Intelligence and Humanized Computing, 11, 663-674. https://doi.org/10.1007/s12652-019-01377-0

[82] Hussain, A., Ullah, K., Mubasher, M., Senapati, T., & Moslem, S. (2023). Interval-valued Pythagorean fuzzy information aggregation based on Aczel-Alsina operations and their application in multiple attribute decision making. IEEE Access, 11, 34575-34594. https://doi.org/10.1109/ACCESS.2023.3244612

[83] Khan, M. S. A., Anjum, F., Ullah, I., Senapati, T., & Moslem, S. (2022). Priority Degrees and Distance Measures of Com-plex Hesitant Fuzzy Sets with Application to Multi-Criteria Decision Making. IEEE Access, 11, 13647 - 13666 https://doi.org/10.1109/ACCESS.2022.3232371

[84] Jabeen, K., Khan, Q., Ullah, K., Senapati, T., & Moslem, S. (2023). An Approach to MADM based on Aczel-Alsina Power Bonferroni Aggregation Operators for q-Rung Orthopair Fuzzy Sets. IEEE Access. https://doi.org/10.1109/ACCESS.2023.3270267